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Technological system and renewable energy policy: A case study of solar photovoltaic in Taiwan

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Abstract

In Taiwan, having implemented some incentive measures and subsidies, some progress of renewable energy in Taiwan has occurred; however, comparing the medium and long-term target reveals a wide gap. This paper (taking the solar photovoltaic (PV) for example), applies the 'technological system' framework to analyze the evolution of PV in Taiwan. Here, a comparative analysis is made of the development of PV between Germany and Taiwan to understand what issues that policy makers should focus on PV utilization in Taiwan.

Keywords: Technological system; Solar photovoltaic (PV)

Contents

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1. Introduction

Renewable energy is a sustainable and clean source of energy derived from nature. The usage and development of renewable energy is flourishing because of shortages in fossil energy, impacts on the environment and energy sustainable usage. Taiwan is an island nation with limited indigenous conventional energy resources, and 97% of its energy is imported. To facilitate domestic energy diversity as well as improve environment quality, the promotion of renewable energy has become an important part of the energy policy in Taiwan.

The policy challenges of renewable energy are considerable since adequate knowledge of these transformation process features from incumbent technologies to renewable energy technologies exist. This study attempts to improve our understanding of the processes involved in the formation and expansion of renewable energy technological systems in the energy sector and to identify the associated inducement and blocking mechanisms for policy makers managing the transformation process. Taking PV for example, 'technological system' framework is applied to analyze the evolution of PV in Taiwan. The development of PV between Germany and Taiwan is comparatively analyzed, with the aim of understanding what issues that policy makers undergo to enhance utilization PV in Taiwan.

2. Analytical framework

Extensively academic literature exists on system change or transformation—whether at an individual or collective act. The process, whereby, a specific new technology emerges, may be studied utilizing the concept of a technological system, which is a technology-specific transformation system and is improved and diffused in society [10]. Technology-specific features of the approach are particularly attractive when the focus of enquiry is on the competition between emerging technologies and incumbent technologies.

According to Carlsson and Stankiewicz [2], a technological system is defined as 'networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology' and is made up of 'actors', 'networks' and 'institutions'.

The analytical relationships between functions and technological system and the system performance are depicted in Fig. 1 [14]. A useful way to analyze the performance of a technological system focuses on how a number of functions are served in the system.

After extensively reviewing innovation system literature, the functions distinguished by Jacobsson and Johnson are chosen for this paper, mainly because these functions have already been tested in many renewable energy researches [11–13]. It suggests that five basic functions need to be served in a technological system [11]:

(1) The creation and diffusion of new knowledge
(2) The guidance of the direction of search among users and suppliers of a technology

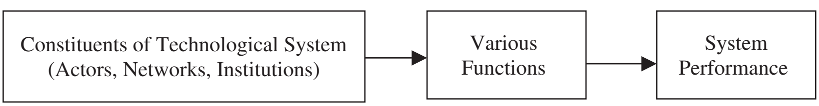

Fig. 1. The framework of technological system.

(3) The supply of resources
(4) The creation of positive external economies, and
(5) The formation of markets.

These functions are not independent of one another, and changes in one function may lead to changes in others. The framework provides an effective means of analyzing the dynamics of a technological system. In addition to studying evolutionary processes in terms of changes in entries and exits, network formation and institutional set-up attention to how the functional pattern of a technological system evolves and what drives its evolution is important. For a transformation of the energy system to occur, new technological systems with powerful functions must emerge around a range of new energy technologies.

The development and growth process of technology system is often explained through product life cycles. The technological system is generally described as consisting of two main phases—a formative period followed by a market expansion-which differ of the character of technical change, the patterns of entry/exit and the rate of market growth [15,16,19].

2.1. Formative period

The existence of a range of competing designs, small markets, many entrants and high uncertainty in terms of technologies, markets and regulations are emphasized with respect to the characteristics of the formative period. Niches or nursery markets are the fundamentals of this period [1]. New entrants into the market, demanding services and therefore bringing more people in can together form an advocacy coalition to alter institutions. Therefore, markets must occur early in the formative stage so that the other stages occur.

2.2. Market expansion

These investments may have generated an adequately large system, which is sufficiently complete to be able to a 'shift gear' in the technological system transformation and begin to develop in a 'self-sustaining' way [13]. For technological system to be linked into larger market opportunities larger markets must form. A virtuous circle then starts. However, such a virtuous circle process will not occur unless the formative period occurred and completed successfully.

Many 'blocking mechanisms' (such as markets may not be formed or network may fail) may operate at the formative phase, or they may also obstruct a transition towards a more self-sustained phase in the technological system. Clearly, if the new technology is to emerge, powerful inducement mechanisms are necessary to overcome this range of potential blocking mechanisms. The nature of both inducement and blocking mechanisms vary between technologies and countries. Section 4 applies the framework to analyze PV and relate how these mechanisms have influenced the five functions in the technological system. The renewable energy target and strategy for Taiwan is outlined in Section 3.

3. Renewable energy target and measures for Taiwan

Taiwan is an island nation with very few indigenous conventional energy resources, and energy imports are over 97%. To facilitate domestic energy diversity as well as improve environmental quality, the promotion of renewable energy has become an important part of the energy policy in Taiwan. The 'National Energy Conference' in May 1998 set a 3% goal for renewable energy utilization by 2020 in Taiwan. After the conference, a group of experts drafted a report on 'The New and Clean Energies Utilization Potential in Taiwan', and the Government of Taiwan committed a NT$10 billions (about US$0.3 billions) budget from 1999 to 2003 toward R&D and promotions of renewable energy and energy conservation [5].

In 2003, the renewable energy development target of Taiwan was amended to enhance the determination towards the utilization of clean energy. The target now is that the share of renewable energy in terms of installed power generation capacity would be more than 12% of the total, or achieving a total of 6500 MW renewable energy power in the medium and long term. Additionally, according to 'Nuclear-free Homeland Action Plan', which is the conclusion of the 'Nuclear-free Homeland Conference' on June 27, 2003, a budget of NT$3 billions (about US$0.09 billions) annually commencing from 2004 for promoting the development of clean energy and energy saving industries to facilitate the achievement of the renewable energy development target [4].

Fig. 2 shows the present renewable energy development target for Taiwan. Targets share for renewable energy in terms of capacity is 12% of the total by 2020. The installed capacity will expand three times of the present exceed 6500 MW (Solar PV will be 1000 MW among the target).

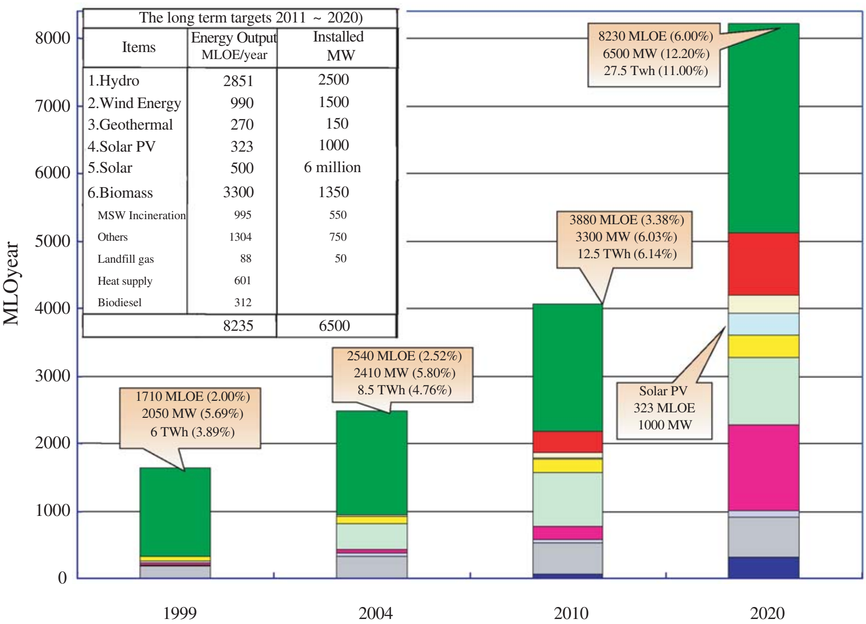

Fig. 2. Renewable energy development target for Taiwan.

To trigger investments from private sectors, and to sponsor local R&D efforts to accelerate the maturity of technologies and the reduction in costs, current incentive measures for demonstration and promotion should continue before the law above is legislated or passed [18]. Table 1 shows current incentive measures for renewable energy. The measures include system subsidy, tax exemption and financial assistance, and subsidy of purchasing electricity [3,8].

Having implemented these incentive measures and provided subsidies, the status of renewable energy up to 2003 is as follows [7].

For solar water heaters, the installed area of heat collectors in Taiwan has reached 1,200,000 m^2. This is the 10th largest installed base in the world.

For PV demonstration systems, 74 applications were approved for subsidies, with an accumulated installation capacity of 512 kWp.

For demonstration systems of wind power, the total capacity that has been approved for subsidization is 8.54 MW.

For geothermal energy, the Energy Commission is working with local government to construct demonstration generation systems with multi-purpose utilization. The target is to assist in promoting at least 5 MW of geothermal power generation in 5 years.

For hydropower, the total installed capacity is around 1900 MW (excluding pump storage hydropower), and the capacity of small hydropower (smaller than 20 MW) is around 130 MW.

For biomass energy, there are more than 70 biomass installations existing with capacities of 486 MW power generations and 920 kton/yr heat productions.

4. Linking the technological system with practice—the formative period

As underlined previously, having implemented some incentive measures and subsidies, some progress of renewable energy in Taiwan has occurred. However, comparing the medium and long-term target (6500 MW) reveals a wide gap. It is necessary to identify these inducement and blocking mechanisms to influence the five functions in the technological system transformation from incumbent technologies to renewable energy technologies. The nature of both inducement and blocking mechanisms vary between technologies, and there are great development potentials for PV in Taiwan. This section takes the PV for example and applies the technological system framework to analyze the evolution of PV in Taiwan. The development of PV between Germany and Taiwan is analyzed to understand what issues that policy makers should do to enhance the utilization of PV in Taiwan.

An emphasis is made on a range of competing designs, small markets, many entrants and high uncertainty in terms of technologies, markets and regulations with respect to the characteristics of the formative period. In Taiwan, besides hydropower and biomass (mostly from incineration of MSW) capacity, other renewable energy share of total installed capacity is insignificant and the market is limited. As underlined previously, the accumulated installation capacity of PV is only 512 kWp. Here, the development of PV in Taiwan is at the formative phase, and begin this analysis by capturing how the function pattern of the technological system evolves.

Fig. 3 illustrates the framework for PV technological system at the formative phase in Taiwan. In Taiwan, current incentive measures for PV promotion include demonstration system subsidy, financial assistance, and subsidy of purchasing electricity. These incentive

Table 1
Current incentive measures for promotion of renewable energy in Taiwan

Incentive measures		Subsidy means	Ratio of subsidy to install cost
System subsidy	Subsidy orders for purchasing solar thermal system (issued January 26, 2000)	Subsided based on type and effective area of collector (in NT$/m^2) Taiwan dist. Islands 1. Civered flat plate: 1500–3000 2. Vacuum tube: 1500–3000 3. Uncovered flat plate: 1000–2500 4. Others: approved by case	15–20%
	Subsidy orders for demonstration of wind power system (issued March 22, 2000)	<NT$16,000/kW (about US$485/kW)	<50%
	Subsidy orders for demonstration of photovoltaic system (issued May 31, 2000)	1. Stand-alone: <NT$110,000/kWp (about US$3333/kWp) 2. Grid-connected: <NT$150,000/kWp (about US$4545/kWp)	<50%
	Subsidy for exploration of geothermal resources (issued September, 2003)	<NT$20,000,000 per site (about US$606,060 per site)	<50%
Tax exemption and Financial assistance	Industry Promotion Laws (Issued October 31, 1999) Investment exemption regulations for companies purchasing energy conservative machines or using machines or technologies by new and clean energy (rev. July 19, 2000)	1.13% Tax credit 2. Two-year accelerated deprecation 3. Low interest loan: discount 2.125% of interest rate of primary loan of Chiao-Tung Bank	—
Subsidy of purchasing electricity		1. Subsidy of NT$0.5/kWh for landfill gas power system (about US$0.015/kWh) 2. Taipower's interim power purchase measure (2003) (1) An interim measure before the 'Renewable Energy Development Bill' is passed by the Congress. (2) Total quota: 300 MW renewable energy (3) NT$2/kWh (about US$0.06/kWh) paid to approved applicants for 10 years can be extended up to 20 years	

measures to invest in PV need to be put in place to stimulate the 'formation of markets' function. Doing so is an attempt to provide 'guidance of the direction of search' for a variety of firms towards the new field and further stimulating the 'creation of new

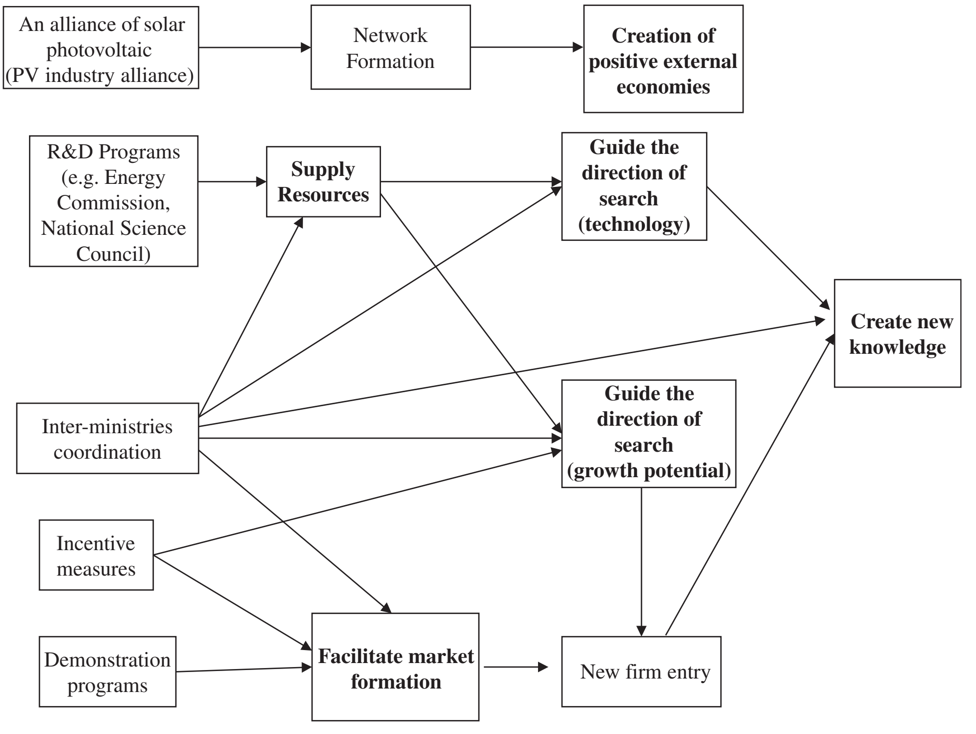

Fig. 3. The PV technological system at the formative phase in Taiwan.

knowledge' function and the formation of prime movers. The incentives absorb some of the technological and economic risks for pioneering suppliers. Other instruments such as demonstration programs in Taiwan have also stimulated the formation of markets function and the creation of knowledge of applied nature.

The research and development programs (e.g. Energy Commission or National Science Council) also provide substantial influence on the function 'supply resources'. Supply resources induce a search into many directions in the general area of PV technologies and broad range of experiments undertaken. The subsequent accumulation knowledge and competence stimulates the creation of variety through an influence on the function creation of new knowledge.

The formation of the alliance could promote renewable energy effectively. The alliance implies the building up of networks. These networks operate within each organization, across them, between different organizations and policy makers. A 'creation of positive external economies' primarily through a process of highly organized work to change the institutional setup in favor of renewable energy is founded. Presently, a number of players in the PV industry within Taiwan exist, with a complete spectrum from the production of ingot for solar cells, manufacturing of solar cells, modules, and system integrator. A recently formed Photovoltaic Industry Alliance joined force with industry, institution, government and academia towards the development and utilization of PV system in Taiwan [17].

Additionally, designing policies that aim to influence the functional pattern of an entire technological system obviously requires co-ordination between various ministries and agencies toward the promotion of emerging systems. In Taiwan, to coordinate all parties toward the promotion of renewable energy through the execution of the 'Renewable Energy Promotion Plan' adopted in January 2002, with an inter-ministries coordination mechanism to resolve all potential barriers and major issues.

Germany has been a leading country both in the allocation of funds to Research, Development and Demonstration (RDD) and, lately, in terms of the diffusion of PV. Fig. 4 illustrates the framework for PV technological system at the formative phase in Germany. This paper also makes a comparative analysis of evolution of PV industry at the formative period between Germany and Taiwan.

The outcome of the formative phase in Taiwan is similar to that of Germany, although the functional pattern in the technological system differs somewhat. In Germany, the Federal RDD policy also provides substantial influence on the function supply resources, and further induces the function creation of new knowledge in many alternative directions and a few firms guide their search process to enter into PV development.

Apart from only one alliance of PV in Taiwan, three types of organization in Germany exist [12]. The first type is a broadly based organization that includes members of the public; the second type of organization is the conventional industry association; the third type of organization is Eurosolar, which is campaigning within the political structure. The formation of three organizations implies the more powerful networks and political power in Germany.

Additionally, the Taiwan government is divided into many ministries and agencies, so more co-ordination efforts between various ministries and agencies toward the promotion of PV exist than in Germany.

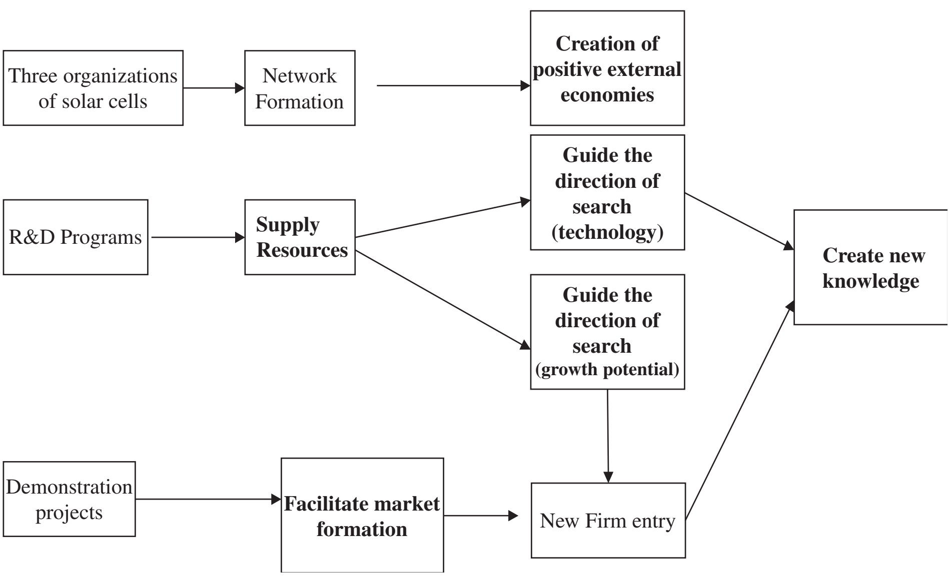

Fig. 4. The PV technological system at the formative phase in Germany.

Overall, at this formative period, whether in Germany or Taiwan, the dominating function is the supply of resources in the form of Research, Development and Demonstration programs. This 'guided the direction of search' into PV and 'created new knowledge' about a range of technological alternatives, and the application of these, in a large number of organizations. Moreover, the formative period allows for a space opening for PV in which a range of firms and academic departments began a process of experimentation and learning. Niche markets are formed and a set of firms are induced to enter. However, the present high costs of power generated by PV means that more generous policies must support diffusion of PV to this application. During the formative period, no virtuous circle could be identified; the process of development of the technological system is not self-sustained.

5. The future market expansion period

A formative stage follows the initial market enlarged space so that volume advantages can be reaped, additional firms be induced to enter throughout the value chain and further learning is stimulated. The challenge to the technological system is to strengthen these virtuous circles so that the growth of the system will be increasingly self-sustained. In Taiwan, when the formative period has completed, for the transformation process is necessary to become a market expansion period (self-sustained) in the future. At the market expansion period, the case of Germany is chosen, for example, since Germany has gone through the formative period and transforms to become the market expansion period. In addition, Germany is very successful for spreading PV. By the end of 2003, cumulative PV installations were approaching 400 MW.

Table 2 summarizes the measures for the PV technological system at market expansion period in Germany. According to the successful experience of diffusing PV in Germany, 'the formation of markets' is at the heart of a process of market expansion period. Drawing on the main measures of the formation of markets in Germany, we can outline three important issues that policy makers in Taiwan should do to further expand the market of PV in the future.

Firstly, implementing pricing policies in market expansion phase which give investors benefits that are powerful (to provide strong incentives and to compensate for the inherently high uncertainties involved), predictable (to reduce uncertainties to a manageable level) and persistent (to allow for long life times of the equipment and a long learning period) [13].

In Germany, in March 2000, the 1991 feed-in law was revised and the remuneration was no longer set as a function of market price, but was fixed for a period of 20 years [12]. In Taiwan, the 'Renewable Energy Development Bill' almost fulfilled these conditions. When passed in the future, the incentive is reasonably predictable as it is anchored in a law, and it is persistent the incentive is made persistent as the law guarantees a price for long period to investors. Hence, to seek rapid passage of Renewable Energy Development Bill is the key factor for expanding the market of PV in Taiwan [6].

Secondly, because each of renewable energy type has different characteristics, the importance of considering local conditions (such as: solar irradiations, land-use areas) to estimate potential of each kind and apply 'cost-benefit analysis' for different renewable energies exists [9]. Furthermore, according to the cost-benefit analysis results design a regulatory framework that includes giving different prices, and price dynamics, for

Table 2
The PV technological system at the market expansion period in Germany

Function	Market expansion period
	Measures (stress on *formation of market*)
The creation and diffusion of new knowledge	Continued federal RDD policy induces the creation of new knowledge (such as several the thin-film technologies)
The guidance of the direction of search among users and suppliers of a technology	Continued federal RDD policy guides in their search process to enter into PV development
The supply of resources	Continued federal RDD policy
The creation of positive external economies	Organization at the formative period, and increased powerful networks between industry and academia
The formation of markets	(1) 1000 roofs program (1990) (2) The further market formation programs aimed at supplying 100,000 roofs with PV and involved investment subsidies and low interest rates for owners of PV (1999) (3) The feed-in law was revised and the remuneration was no longer set as a function of market price, but was fixed for a period of 20 years (2000) (4) Moreover, the remuneration differed between various renewable energy technologies. For solar power, this increase in payment to 99 pfennig/kWh (about NT$20/kWh)

electricity generated by different renewable energy types. In Germany, the remuneration differs between various renewable energy technologies, for PV, this increase in payment to 99 pfennig/kWh (about NT$20/kWh) [12]. The initiative to form markets resulted in cumulative PV installations of the German market increasing from 54 MW in 1998 to approaching 400 MW in the end of 2003.

In Taiwan, the cost to install PV capacity is about NT$300,000/kW (US$9000/kW), as a result, the levelized cost is about NT$14/kWh (US$0.42/kWh) at present. The price of electricity in Taiwan is pretty cheap (NT$2.3–3.1/kWh (US$0.07–0.09/kWh) for residential use in average). If Government plans to follow Germany by setting promising prices for PV (NT$20/kWh), unless revising the current price of electricity structures, the fairness and financial feasibility would be a question mark. However, considering the development potential of PV in Taiwan, apart from a general price guarantee for each kilowatt per hour anchored in the Renewable Energy Development Bill, Government could also subsidize for the equipments of PV and set gradual targets to diffuse PV step by step. If the structure of the price of electricity changes or the cost of PV declines significantly in the future, it would be feasible to design a regulatory framework that includes giving different prices for electricity generated by different renewable energy types in Taiwan.

Thirdly, a strengthening of the expanding market for PV in the market expansion period should occur. In Germany, in January 1999, the 100,000 roofs program with PV started, providing investment subsidies and low interest rates for owners of PV. In Taiwan, it is necessary to form the further market expand programs in the medium and long-term.

Additionally, to response to future growing market, in which ranges of entrants enter to enlarge the technological system, a more detailed division of labor within the PV industry

should form. In the future, the entry of more firms into the whole value chain should be included, i.e. silicon suppliers, wafer producers, cell producers, system engineering firms, application specialists, firms supplying building integrated photovoltaic, architects and electricians. These firms will require resources, to experiment with the new technology and to learn as well as teach the new technology. Networks strengthening will enhance the learning. In addition to these firms, educational institutions, financial institutions, insurance companies, city planners need to learn about PV and to develop a policy. Without prior extensive learning, diffusion on a large scale will simply not be able to take place.

6. Conclusions

Renewable energy is a sustainable and clean source of energy derived from nature. The usage and development of renewable energy is flourishing because of shortages in fossil energy, impacts on the environment and energy sustainable usage. Taiwan is an island nation with limited indigenous conventional energy resources, and 97% of its energy is imported. To facilitate domestic energy diversity as well as improve environment quality, the promotion of renewable energy has become an important part of the energy policy in Taiwan.

In Taiwan, having implemented some incentive measures and subsidies, some progress of renewable energy in Taiwan has occurred. However, comparing the medium and long-term target reveals a wide gap. This study takes PV for example and applies the technological system framework to analyze the evolution of PV in Taiwan. The development of PV between Germany and Taiwan is analyzed to understand what issues that policy makers should do to enhance the utilization of PV in Taiwan. At the formative period, the analytic result shows the outcome of the formative phase in Taiwan is similar to that of Germany. The dominating function is the supply of resources in the form of Research, Development Demonstration programs. Additionally, the formative period in Taiwan not only opens a space for PV in which a range of firms and academic departments begin a process of experimentation and learning, but also forms niche markets so that a set of firms are induced to enter.

At the future market expansion period, Germany's successful experience indicates the formation of markets is at the heart of the process. Drawing on the main measures of the formation of markets in Germany, three issues are outlined that policy makers in Taiwan will need to do to further expand the market of PV in the future. (1) 'Implement pricing policies which are powerful, predictable and persistent': In Taiwan, the Renewable Energy Development Bill almost fulfilled these conditions. Hence, to seek rapid passage of Renewable Energy Development Bill is the key factor for expanding the market of PV in Taiwan. (2) 'Designing different prices for different renewable energy': The price of electricity in Taiwan is pretty cheap. If Government plans to follow Germany by setting promising prices for PV, unless revising the current price of electricity structures, the fairness and financial feasibility would be a question mark. However, considering the development potential of PV in Taiwan, apart from a general price guarantee for each kilowatt per hour anchored in the Renewable Energy Development Bill, Government could also subsidize for the equipments of PV and set gradual targets to diffuse PV step by step. (3) 'A further expanding market for PV': In Taiwan, it is necessary to form the further market expand programs in the medium and long-term.

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